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Re: Optimizing Fuel Volume Density...

- *To*: STOVES@crest.org, seasweep@seasweep.com, "'=Mr Tom Reed'" <Reedtb2@cs.com>
- *Subject*: Re: Optimizing Fuel Volume Density...
- *From*: Weststeijn A <A.Weststeijn@epz.nl>
- *Date*: Fri, 9 Feb 2001 23:50:24 +0100
- *Cc*: ETHANOL@crest.org, bioenergy@crest.org, gasification@crest.org, BIOCONVERSION@crest.org
- *Delivered-To*: mailing list bioenergy@crest.org
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Dear Tom Reed and List members,

Glad to comment on the issue of volumetric density. Tom invited me to give

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an essay on the effect of energy volume density on storing and feeding.
Here it is.
My chain of thought goes from macro to micro and ends with fuel data and example calculations of volumetric impact on maximum cofiring percentages.

1. VOLUMETRIC DENSITY

I fully support Tom Reed's suggestion to emphasize the volumetric energy density of biofuels (GJ/m3 or MMBtu/ft3) and give it an equal place next to the mass based energy density (CV in GJ/ton or MMBtu/lb). Volumetric energy density is important both from a design and from an economics point of view. And ought to be considered for the complete fuel cycle.

2. INTEGRATED FUEL CHAIN

Use of biomass fuels on a scale as required to impact the world's GHG balance requires hugh material flows. Flows in tons, but in volume as well. To manage this material flow (and keep it within financial constraints) an integrated view of the complete fuel chain is required, much like the overviews used for LCA's (Life Cycle Analyses).
The economical viability of any fuel chain will be determined by the partial costs per link. Picking the right links to string a complete chain is what matters most.
Given the comments by Tom Miles, I will not address the transportation issue. I just like to add that also barge and blue-water ocean traffic underly Tom Miles's observation stressing optimum loose bulk density as based on volume versus weight transportation rates. Some biomass is crossing blue water already.
The fuel chain requires to separate "new" from "existing" power plants.

3. NEW versus EXISTING PLANTS

Designing a dedicated plant for a dedicated (bio)fuel is one thing. Helping to make a dent in the GHG increase world wide is another. I believe that both routes need to be explored simultaneously to get meaningfull results during the next decades.

(For those who don't like GHG concern, substitute regular fossil fuels depletion, it leads to the same conclusion).

3A. New plants and new independent add-on fuel systems

For a new plant (or new independent fuel circuit feeding directly into the boiler) there is the classic design choise: can more expensive (densified) fuel provide for lower than proportional capital charges or not? The answer: probably yes, but modestly in as far as sizing of the equipment is concerned.
Unloading facilities, interim storage and feeding mechanism can all be more compact, and somewhat less construction materials used. However, whereas total weight to be transported and stored is unchanged, the savings on construction materials (and related investment) will be modest. Clearest case of lineair savings will be in the roofing of covered storage (not in the foundations, weight is unchanged). No savings foreseen in automation, process controls etc. No savings are foreseen in operations and maintenance.
Note: max. capacity is not a concern in this equation
For a new plant on an unconstricted site my guess is that the financial gain by designing for densified fuel will only be modest.
With two exeptions:
1) site space limitations don't allow for undensified storage
2) densification of biofuel allows it to be handled
These two exeptions don't deal with a free cost/benefit choice, but rather are a prime prerequisite for the execution of the particular project.

3B. Existing plants

Here physical constraints are to be faced in terms of steel and concrete. Not just on the drawing board. Two options are open: "rebuild" or "make-do". A complete rebuild of the existing fuel facilities will often be considered not viable for an existing plant with limited residual life expectancy (boiler, turbine/gen set etc). Where downtime of the unit is not desirable due to contractual dispatch obligations or peak-power earnings potential, a full rebuild can be ruled out and "make-do" will be the preferred option. Remember, converting to biomass as cofiring fuel is usually a financially marginal operation. In cases of an existing coal infrastructure, the decision will often be based on a mix of reasons (certainly including environmental incentives), hardly expecting to cover much more than costs.

That leaves to "make-do" with the existing facilities.
-For unloading of biomass the limitation will often not be so strict, if unloading with help of the coal unloading facilities. Chances are good that at present there is enough spare time for handling the incremental volume.
-For storage the same holds true as for the newly designed plant: cost of foundations will change little, cost of roofing (if required) will decrease almost linearly with degree of densification. If storage space is limiting the project, densification might be a prerequisite.
-It is in feeding biomass with help of the existing coal feeding system that the impact of volumetric density shows up most clearly. Conveying, storage in the boiler house, feeders, pulverizers, classifiers (sieves) all can become volume restricted.
Running conveyor belts more hours around the clock has its limitations due to maintenance requirements. Not only for the belts and drives itself, but also for the loading, weighing and unloading equipment at both ends. Loading up belts higher is limited by angle (both cross-sectional and elevating towards the boiler house), dump shoots may plug up.
Still it is also here that real potential for bulk biomass cofiring opens up, due to the low degree of modifications required, with subsequent low capital charges involved.

4. NUMERICAL COMPARION of FUEL DATA (in metric)

COAL
loose bulk density = 850 kg/m3 (in pile)
energy density CV= 24 MJ/kg = 24 GJ/ton
volumetric density = 850 kg/m3*24 MJ/kg
volumetric density = 20400 MJ/m3
volumetric density = 20.4 GJ/m3

LOOSE DRY SAWDUST
loose bulk density = 200 kg/m3
energy density CV= 18 MJ/kg (assume dry)
volumetric density =200 kg/m3*18 MJ/kg
volumetric density = 3600 MJ/m3

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volumetric density =  3.6 GJ/m3

REGULAR WOOD PELLETS
"solid" density = 1.3 g/cc
"solid" density = 1300 kg/m3
in pile: void coefficient = 50%
loose bulk density = 650 kg/m3
energy density CV= 18 MJ/kg (assume dry)
volumetric density =650 kg/m3*18 MJ/kg
volumetric density = 11700 MJ/m3
volumetric density = 11.7 GJ/m3

THERMALLY UPGRADED WOOD PELLETS
"solid" density = 1.3 g/cc
"solid" density = 1300 kg/m3
in pile: void coefficient = 50%
loose bulk density = 650 kg/m3
energy density CV= 22 MJ/kg (assume)
volumetric density =650 kg/m3*22 MJ/kg
volumetric density = 14300 MJ/m3
volumetric density = 14.3 GJ/m3

Comparison:
coal = ..................................... 20.4 GJ/m3
loose dry sawdust = .............. 3.6 GJ/m3 or 18% of coal
regular wood pellets = ........ 11.7 GJ/m3 or 57% of coal
therm.upgraded pellets =......14.3 GJ/m3 or 70% of coal

Relative volumetric energy density:
coal = .....................................   1.00
loose dry sawdust = .............. 0.18
regular wood pellets = .......... 0.57
therm.upgraded pellets =......  0.70


5. EXAMPLE CALCULATION of volumetric impact
with wood pellets at 50% fuel flow volume increase

Suppose one handles in an existing (or slightly modified) plant a physically
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maximum volume of mixed fuel of coal+regular wood pellets. And still feed the boiler with an equal amount of energy (same # GJ's) on a 24-hour basis.
For the sake of this example calculation, assume that that physically maximum volume equals 150% of the volume of 100% coal.
How does this work out on the allowable percentage cofiring of wood pellets, the reduction in coal and the cofiring percentages.
The relevance of densification is shown in paragraph 6 when we scale back from densified wood pellet to non-densified sawdust.

Whereas one now bunkers 150% of the original volume, the averige "volumetric energy density" of the mixed fuel may now be reduced to 2/3 of what it was for pure coal, i.e. may go down to 0.67*20.4 GJ/m3=13.7 GJ/m3.

*First consider from a mass flow + energy input point of view:

equation for coal energy per 24-hours:
coal X ton/24h*24 GJ/ton = 24X GJ/24h

equation for coal+wood pellets energy per 24-hour:
coal Y ton/24h*24 GJ/ton + pellets Z ton/24h*18 GJ/ton =
(24Y+18Z) GJ/24h

These fuels represent the same energy per 24-hours,
24X=24Y+18Z
pellet mass flow Z=(24/18)*(X-Y) tons/24h
(equation 1)

*Now from a volume point of view:

equation for coal volume per 24-hours:
coal U m3/24h

equation for coal+wood pellets volume per 24-hours:
coal V m3/24h + pellets W m3/24h
V+W m3/24h

*We assumed the mixed fuel to have a factor 1.5 higher volume:
therefore: 1.5*U=V+W m3/24h
pellet volume W=1.5U-V m3/24h

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(equation 2)

For pellets the ratio Z tons/24h over W m3/24h = specific weight
Z/W = 0.650 or Z=0.65*W

For 100% coal the ratio X tons/24h over U m3/24h = specific weight
X/U = 0.850 or U=X/0.85
For reduced % coal the ratio Y tons/24h over V m3/24h = spec weight
Y/V= 0.850 or V= Y/0.85

Substitute the above ratio's in equation 2 and find:
W=1.5U-V
Z=0.65*(1.5X/0.85-Y/0.85)
(equation 3)

we had equation 1 as:
Z=(24/18)*(X-Y)

Follows from equation 1=equation 3:
> (24/18)*(X-Y) = 0.65*(1.5X/0.85-Y/0.85)
X-Y = (18/24)*(0.65/0.85)*(1.5X-Y)

for a better overview call  factor F = (18/24)*(0.65/0.85)
X-Y = F*(1.5X-Y) = 1.5FX-FY
follows FY-Y = 1.5FX - X
Y(F-1) = X (1.5F-1)
Y = X*(1.5F-1)/(F-1)
(equation 4)

substitute in equation 1:
Z=(24/18)*(X-Y)
Z=(24/18)*(1- (1.5F-1)/(F-1))*X
Z=(24/18)*(-0.5F/F-1)*X
Z=(24/18)*(0.5F/1-F)*X
(equation 5)

In this particular case of coal and wood pellets:
F = (18/24)*(0.65/0.85) = 0.57
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So that
Z=(24/18)*(0.5F/1-F)*X      (equation 5)
Z=(24/18)*(0.5*0.57/0.43)*X = 0.88 X tons/24h

and
Y= X*(1.5F-1)/(F-1)            (equation 4)
Y= X*(-0.14)/(-0.43) = 0.34 X tons/24h

Y+Z = 0.88+0.34 = 1.22 X tons/24h

where:
Z= wood pellets in tons/24h in mixed fuel
Y= adjusted coal in tons/24h in mixed fuel
X= original coal in ton/24h (as 100% coal)

Subconclusion:
when energy input stays the same
and volume of fuel is allowed to go up to 150%
then in case of densified wood pellets with CV=18 MJ/kg
total tonnage goes to 122%
and cofiring mixture on a mass/mass basis
can reach up to 0.88X / 1.22X = 72%
and cofiring mixture on energy basis
can reach up to (0.88*18) / (0.88*18 + 0.34*24) =  66%


6. NOW FOR THE INFLUENCE OF DENSIFACTION

Under the same assumption of a 150% higher fuel flow volume we now scale
back from dry densified wood pellets with a loose bulk density of 650 kg/m3
to dry non-densified sawdust pellets with a loose bulk density of 200 kg/m3.
In both cases the  CV is kept at 18 MJ/kg.
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- Next by Date: **Fwd: 1st International Congress on Biomass for Metal Production**

[& Electricity Generation]

- Prev by thread: **Re: Optimizing Fuel Volume Density...**
- Next by thread: **Biomass Conference of America Abstracts Due March 16**